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WO 97/06396 A1 US 5636380 A US 5113666 A US 4807447 A

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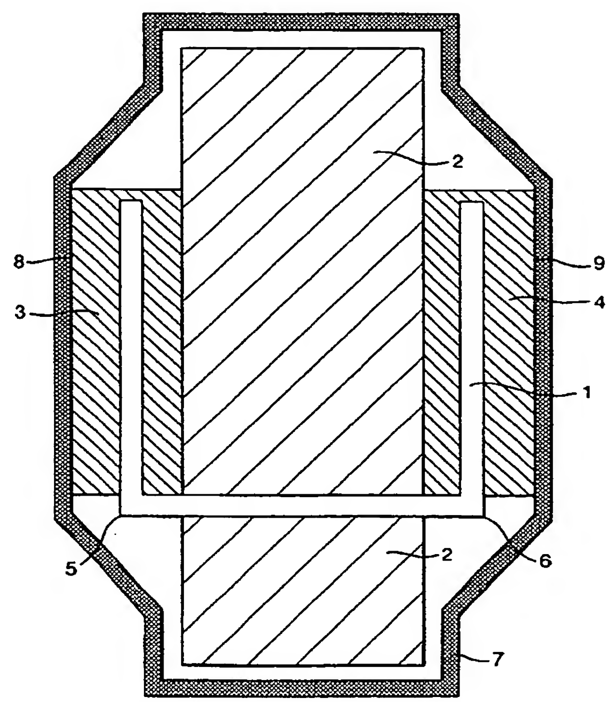
(54) Abstract Title
Thermal management system for clothing

(57) A garment (2) incorporates a means for removing heat and sweat from the surface of the wearer's body. Cooling is achieved through heat transfer conduits such as heat pipes (1) having a first end attached to a collector plate (3) in thermal contact with the body and a second end attached to a dissipater plate (4) remote from the body. The second end of the heat transfer conduit is actively cooled by the evaporation of sweat which is transferred away from the body and through or around the garment by means of a fluid conduit such as a wicking textile (7).

Fig.1.



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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

Fig.1.

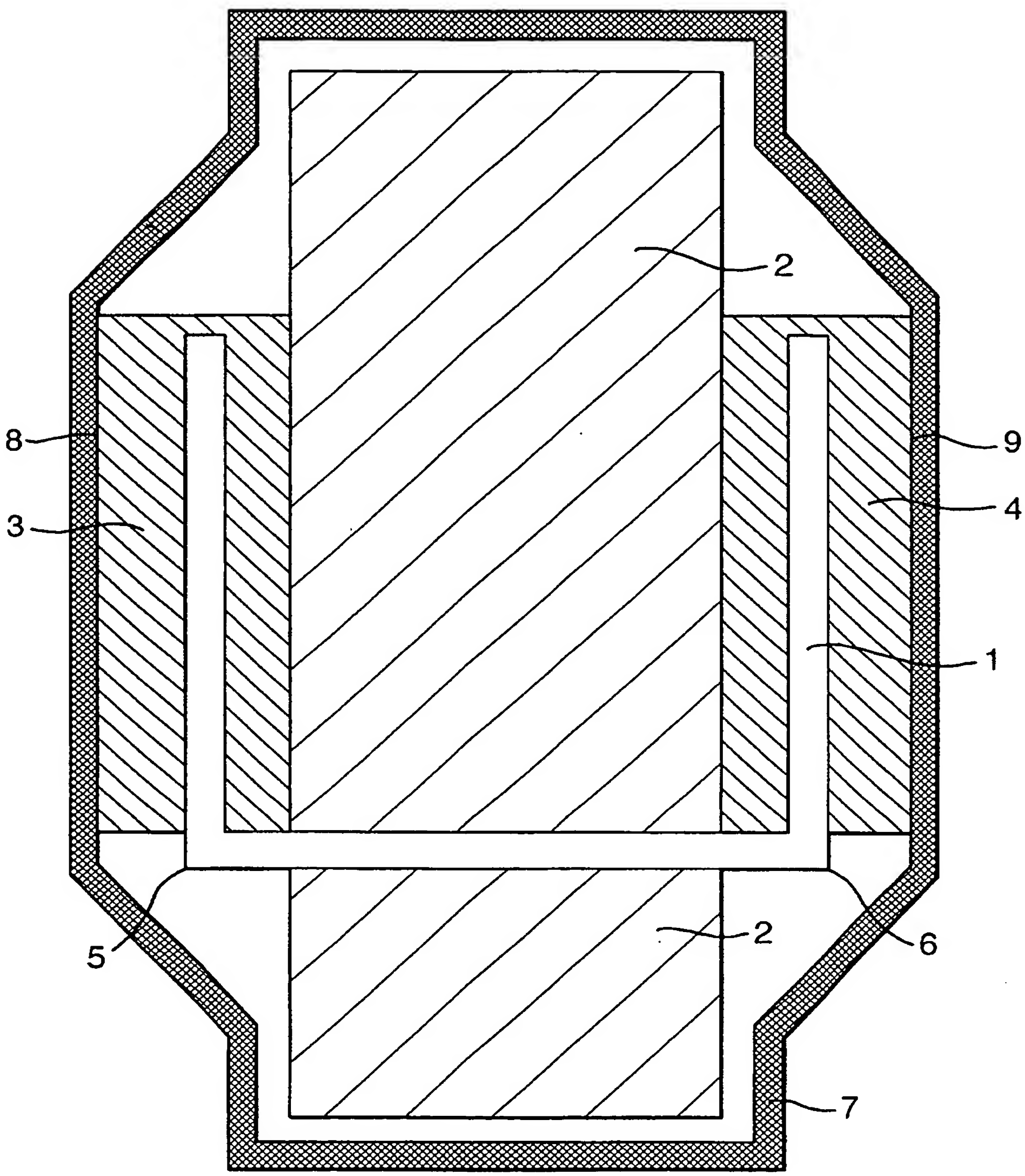


Fig.2.

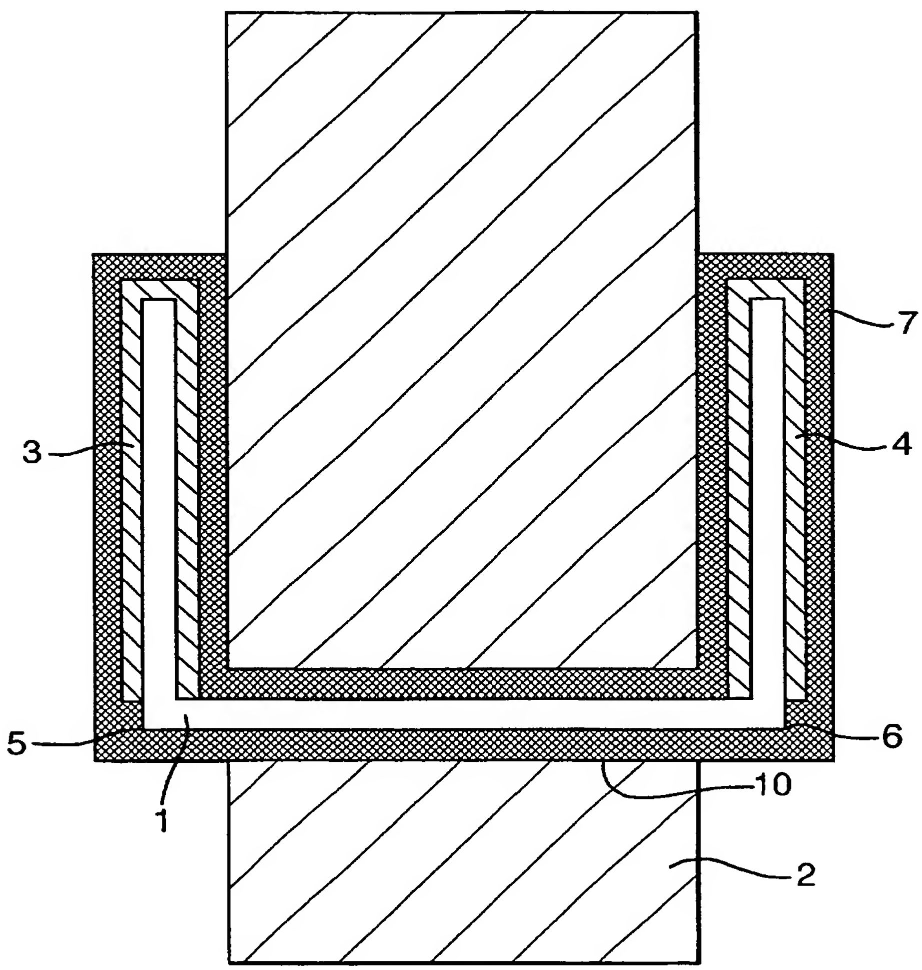
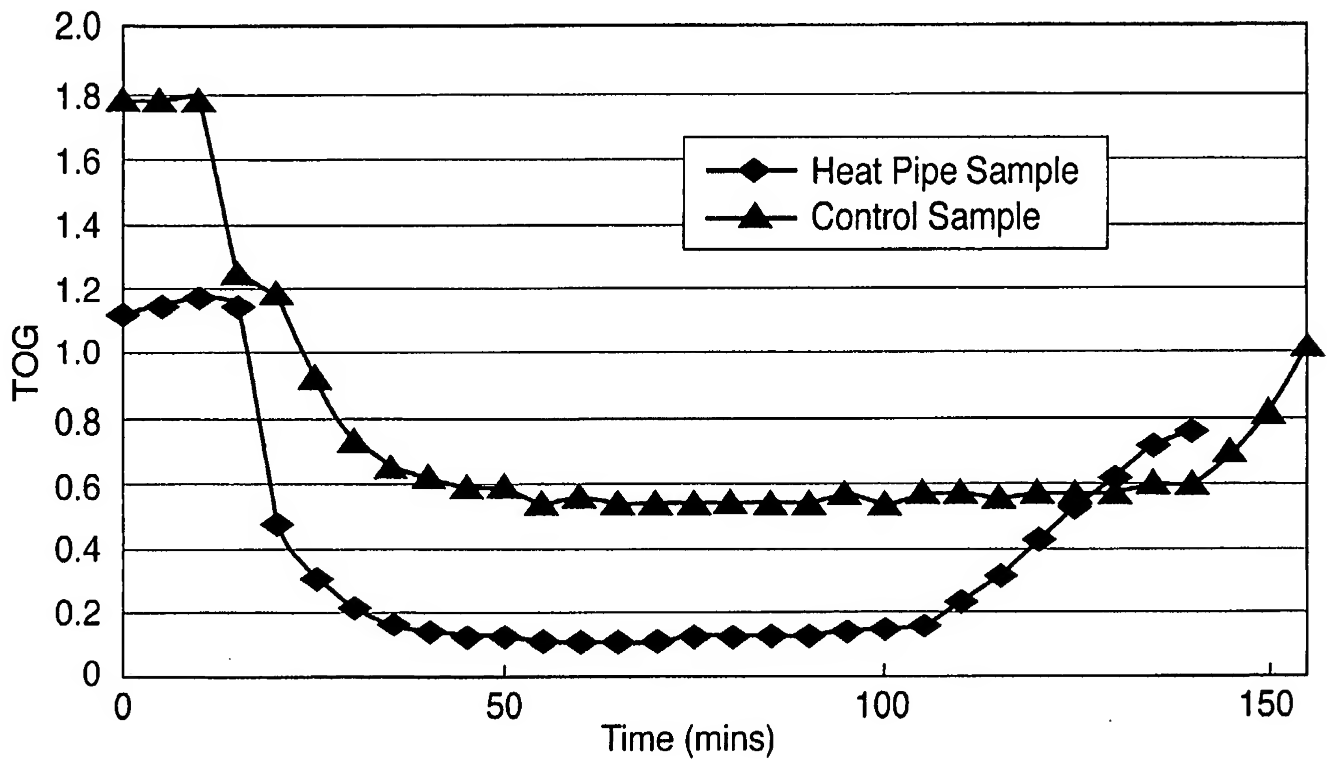


Fig.3.

Graph of Tog vs. Time showing effect of addition of Wicking Fluid after approximately 10 min.



THERMAL MANAGEMENT SYSTEM FOR CLOTHING

This invention relates to a garment capable of removing heat and sweat from the surface of the wearer's body.

Heat stress can arise through wearing protective clothing such as body armour which is inevitably thermally insulating. Hitherto in the art, the problem of heat stress arising from insulative clothing has been addressed through the use of refrigeration units that cool a circulating fluid which is actively pumped through the clothing.

The Australian Defence Institute (ADI) have recently revealed prior art which is referred to as the Australian Individual Protective Cooling System - or IPECS - in respect of a method and apparatus for cooling military combat clothing (*IPECS brochure, Australian Defence Industries Ltd*). The cooling mechanism of IPECS is reliant upon an external refrigeration unit and a cooling fluid which is actively pumped through the clothing.

Protective clothing which incorporates an external refrigeration unit may suffer in terms of utility and functionality on four accounts. First, external refrigeration units are additionally bulky and cumbersome - a disadvantage in the field and a factor which compounds the inherent bulky and awkward nature of protective clothing itself.

Second, external refrigeration packs require a power source to maintain refrigeration. A separate battery source increases the overall weight of the equipmentleading to reduced manoeuvrability. Furthermore, reliance upon an external power source with a limited life span confers an inherent vulnerability upon the wearer.

Third, fragile fluid conduit pipes that circulate coolant fluids can be damaged leading to leakage and lack of operational performance in the field.

Fourth, and finally, the prior art does not provide for a mechanism of sweat removal from the body surface. An excessive build up of sweat against the body surface can cause considerable discomfort to the wearer which again will detract from the performance of the wearer when used in operation.

Protective clothing such as body armour is thick and bulky and as a result is highly insulative to heat transfer. Under hot or stressful conditions heat and sweat can build up between the inner surface of the protective garment and the body surface of the wearer. This can lead to discomfort which can detract from the normal operational performance of the wearer. In the last resort and under extreme conditions such clothing can lead to severe heat stress which can be life threatening.

There is therefore a need for self cooling protective clothing which is not reliant upon an external refrigeration pack and which maintains a steady and safe micro-climate for the wearer under conditions that would, in the absence of the cooling mechanism, lead to severe heat stress and sweat build up. Such a protective clothing system would need to be self contained and comparatively light and easy to wear but without significant reduction in the protection offered by the clothing.

Accordingly a garment is provided with means for removing heat and sweat away from a wearer and across the garment wherein the means comprises at least one heat transfer conduit having a first end in thermal contact with the

wearer and a second end remote from the wearer and at least one fluid conduit which is configured for moving sweat from the wearer to the second end of the heat transfer conduit wherein said sweat assists in driving heat transfer along the heat transfer conduit through evaporation.

The cooling mechanism operates by enabling fluid and heat generated at the body surface to be transferred across the garment. The cooling mechanism is initially activated through the generation of fluid at the body surface. This fluid is transferred around or through the garment by way of a fluid conduit from the body surface to the exterior surface. The fluid that has been transferred from the body surface subsequently evaporates on exposure to the atmosphere - the effect of which is to cool the exterior surface.

Cooling the exterior surface in turn cools one end of a thermal conductor. As the other end of the thermal conductor is in thermal contact with the hot body surface this causes or accentuates a temperature differential between the two ends of the thermal conductor. The heat gradient thus created drives thermal conduction along the thermal conductor from the hot body to the exterior. In such manner both heat and fluid are removed from the body surface despite the presence of an insulative material that would otherwise be impermeable to both.

The cooling mechanism is therefore activated by the body's own thermal regulation system which requires no external energy source and is controlled by an intrinsic on-off switch according to the thermal demands of the body.

Typical garments that are suitable for this configuration of cooling comprise protective clothing that is highly

thermally insulative such as body armour, protective fire suits or NBC (Nuclear, Biological and Chemical) suits.

Appropriate thermal conductors would be heat pipes or other thermally conducting or semi-conducting materials such as silver, copper or conducting polymers which are capable of rapidly and efficiently removing heat from a body surface. Preferably heat pipes are employed as these are found to conduct heat far more rapidly than metal conductors.

In addition the effectiveness of such thermal conductors is enhanced through the use of flat thermally conducting plates which are located at each ends of the thermal conductor. These collector and dissipater plates can be discrete or alternatively can form a uniform layer over the inside and outside of the garment thereby forming a thin but flexible layer or foil over the garment. These flat surfaces can themselves provide extra protection to potential stab injuries where the flat surfaces are interlocking metallic plates or high velocity projectile protection where the plates are conductive ceramics.

Appropriate fluid conductors would be wicking fabrics such as wicking polyester or polypropylene. These materials provide an enhanced capillarity to fluid flow and are a highly effective means of transporting fluids from wet bodies.

Preferable the fluid conductor would be configured so as to remove fluid from the body by transporting fluid around the garment. Alternatively, or additionally, the fluid would be transported across the garment through penetrating the garment. In the latter configuration fluid channels with impervious linings could be utilised.

An advantage of the current invention is that the thermal resistance of the garment to heat flow is dramatically reduced. Indeed under simulated experimental conditions the thermal resistance of body armour has been found to drop by over an order of magnitude.

Another advantage of the current invention is that the cooling mechanism is located directly within the clothing. This circumvents the need for a separate refrigeration device thereby rendering the cooling system more compact. As a result, the wearer is less burdened with cumbersome equipment - an important consideration in combat or other situations where manoeuvrability and fast response is required.

Another advantage flowing from an inherent cooling system is that the need for potentially fragile coolant pipes, both between the refrigeration pack and the clothing, and within the refrigeration pack and the clothing, can be dispensed with. As a result, the wearer is far less vulnerable to heat stress indirectly arising from equipment damage.

In respect to bulky protective clothing such as body armour, the wearer is already significantly encumbered, and therefore a separate refrigeration pack merely serves to increase the burden on the wearer. Furthermore, no vulnerable connection in the form of coolant pipes is required within the clothing or between the clothing and the refrigeration pack.

A further advantage is that the cooling system is driven by the body's own cooling mechanism. That is, it requires no external power source. The system is therefore not dependent upon the life span of an external power source.

Yet another advantage which flows from the reliance of the invention upon the body's own cooling mechanism is the provision of a system with its own intrinsic switch for cooling. This inherent switch mechanism is activated under conditions of heat stress through sweat wicking but is deactivated under conditions where no cooling is required. The system therefore remains in dynamic equilibrium with the body's heat needs without requiring external activation by the wearer.

Yet a further advantage of the current invention is the presence of a wicking conduit which allows sweat to be removed from the body surface thus reducing discomfort to the wearer under prolonged usage.

Yet a further advantage of the invention is rendered through the use of coolant and dissipater plates which are in thermal contact with the heat pipe. These form sheets of metal or thermally conductive ceramic attached to the inner and exterior surfaces of the clothing. This has the effect of increasing the protection afforded to the wearer by conferring stab or high velocity projectile resistance to the clothing material.

Two embodiments of the invention will now be described by way of example and with reference to the accompanying drawings in which:

Figure 1 is a cross sectional view of protective body armour illustrating the incorporation of a heat pipe transversely through the body armour in conjunction with the surrounding external wicking material.

Figure 2 is a cross sectional view of protective body armour illustrating an alternative embodiment whereby the wicking material penetrates transversely through the body armour.

Figure 3 is a graph to illustrate the effectiveness of the heat pipe system compared to a control sample when the outer surface is exposed to water and the water is allowed to evaporate.

Figure 1 illustrates the apparatus which incorporates the essential coolant system design. The figure shows a single heat pipe (1) penetrating and extending through Combat Body Armour (2) (CBA) (UK/5C5108C) (Typically, CBA is made from an aramid or ballistic nylon). The heat pipe is of a standard steel design [2mm x 95mm] which can be obtained from Isoterix Limited, Industrial Estate, Wooler, Northumberland, N67 6SL.

Attached to each end of the heat pipe are located chrome plated copper plates that assist heat transfer along the heat pipe by providing a large surface area for heat flow - these are referred to in figure 1 as the metal collector (3) and dissipater (4) plates.

The figure illustrates that at the interior (5) and exterior (6) surfaces of the body armour the heat pipe is bent approximately at right angles such that it lies along the interior and exterior surfaces of the body armour. As the location of the bend of the heat pipe coincides with the join of the plates to the heat pipe this configuration allows the collector and dissipater plates to lie along the plane of the interior and exterior surfaces of the body armour, thereby forming an outside and inside metallic layer.

The figure further illustrates a fabric material (7) that surrounds the interior and exterior surfaces of the body armour - referred to as the wicking textile cover. This fabric is made of a highly wicking polyester knit textile (or, alternatively, a wicking polypropylene) which adjoins and is attached to the interior (8) and exterior

(9) surfaces of the body armour. The wicking material extends around the protective body armour in the form of a sleeve thereby totally enclosing the body armour - in operation the wicking material attached to the inside of the protective garment provides the first point of contact between the body surface and protective armour, thereby transmitting fluid from the body surface to the exterior surface of the garment.

Figure 2 illustrates a second embodiment of the invention whereby the wicking textile (7), instead of surrounding the protective body armour, penetrates the protective body armour through a transverse fluid conduit (10).

Figure 3 demonstrates the effectiveness of the invention using the configuration shown in figure 1 with a sheet of body armour (UK/5C5108C) and wicking textile (Polyester knit) incorporating nine heat pipes (2mm x 95mm from Isoterix limited). The graph shown illustrates the results of two experiments. The first experiment illustrates the effectiveness of using a high wicking cover around the combat armour with a wicking fluid.

The second experiment illustrates the effectiveness of using the heat pipes through the body armour in conjunction with a high wicking cover and a wicking fluid (distilled water). The difference between the first ten minutes of the results for both tests shows the reduction in insulation due to heat pipes alone without the evaporation of a wicking fluid to help dissipate the transferred heat.

The results obtained are a simulation of the effects that would theoretically be obtained from a sweating body under heat stress where sweat has fully wicked around from the first surface to the second surface. The results were obtained using a togmeter test (BS4745 1990

Thermal Resistance, One Plate Mode) in conjunction with a simulation of the effect of sweat wicking from the inner surface to the outer surface of the protective garment.

The first 10 minutes of the graph indicates that the incorporation of heat pipes into body armour alone has a significant effect on the cooling of the garment. The graph shows that a piece of body armour without heat pipes incorporated (the control sample) - the upper curve - has a tog value of approximately 1.8 tog whereas a piece of body armour incorporating heat pipes (the lower curve) under the same conditions has a tog value of 1.2 tog - still equivalent to a fleece pile jacket but a significant reduction of 0.6 tog.

After 10 minutes both the heat pipe sample and the control sample had their interior and the exterior surfaces of wicking material dampened with distilled water to simulate the effects of wicked sweat onto the two surfaces. The interior surface was then replaced on the heated plate of the togmeter heated and the tog value of the body armour was measured.

The optimum effect is shown at approximately the 50 min mark on the graph. The control sample was found to have a tog value of 0.5 tog - a very significant reduction but still equivalent to two pieces of clothing such as a substantial shirt and a vest. The heat pipe sample was found to have a tog value of 0.1 tog - an equivalent reduction but a significantly lower tog value than that achieved for the control sample - a value of 0.1 tog being equivalent to the lightest shirt or vest.

The results clearly demonstrate that the incorporation of heat pipes in conjunction with an evaporating wicking fluid can have a marked effect on the thermal resistance of a piece of insulative clothing through reducing the

tog value of body armour from 1.8 tog to 0.1 tog thereby rendering the thermal resistance of what is normally a highly thermally insulative material to the tog value of a light shirt.

CLAIMS

1. A garment with means for removing heat and sweat away from a wearer and across the garment wherein the means comprises at least one heat transfer conduit having a first end in thermal contact with the wearer and a second end remote from the wearer and at least one fluid conduit which is configured for moving sweat from the wearer to the second end of the heat transfer conduit wherein said sweat assists in driving heat transfer along the heat transfer conduit through evaporation.

2. An apparatus according to claim 1 wherein said or each heat transfer conduit comprises a heat pipe element.

3. An apparatus according to claim 1 or claim 2 wherein said or each heat transfer conduit additionally comprises a collector and a dissipater plate located respectively at the first and second ends of the heat transfer conduit.

4. An apparatus according to anyone of claims 1-3 wherein said or each fluid conduit is a wicking material.

5. An apparatus according to anyone of claims 1-4 wherein said fluid conduit comprises a sleeve enclosing the garment.

6. An apparatus according to claims 1-5 wherein said or each fluid conduit penetrates transversely a thermally insulative garment.

7. An apparatus for removing heat from the wearer substantially as herein before described with reference to figures 1 and 2.

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Application No:	GB 9917172.0	**Examiner:**	Barnaby Wright
Claims searched:	1-7	**Date of search:**	19 October 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): A3V

Int Cl (Ed.6): A41D (13/00, 31/00), F41H 1/02

Other: Online: EPODOC, WPI, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	WO 97/06396 A1	A.R.M.I.N.E.S. See whole document, especially figs. 1, 5-7	
A	US 5636380 A	SCHINDLER AND DUNCAN See especially figs. 1-5, and col 1, ln 66 to col 2, ln 6 and col 3, ln 23-25.	
A	US 5113666 A	MAINSTREAM ENGINEERING CORP. See especially figs 1, 8 & 9, and col 1, ln 57 to col 2, ln 2, and claim1.	
A	US 4807447 A	MACDONALD See especially fig. 3 and col 2, ln 1-4.	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		